Impact of Foliar Application of Nano Nitrogen and Nano Zinc on Soil Properties of Mustard (*Brassica juncea* L.) Crop

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ABSTRACT

The utilization of nano-sized nitrogen (N) and zinc (Zn) fertilizers through foliar application has gained considerable attention in agricultural research. This study focuses on investigating the effects of such foliar applications on soil properties, including both chemical and biological aspects, after the harvest of mustard (*Brassica juncea* L.). The field experiment was carried out during October to March 2022 season at Instructional Farm, Rajasthan College of Agriculture, MPUAT, Udaipur which lies in agro-climatic zone IV-A of Rajasthan, India. The field was designed in a randomized block design having 10 treatments which were replicated thrice. The treatments include the various combination of RDF and nano fertilizers of N and Zn. The application treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) has significantly increased the availability of macronutrients (N, P, K), micronutrients (Zn, Fe, Cu, and Mn), microbial population (bacteria, fungi and actinomycetes) as well as the dehydrogenase and acid phosphatase enzyme activity in post-harvest soil of mustard over control.

Keywords: Foliar application, Nano fertilizer, Mustard, Microbial population, Enzyme activity

1. Introduction

Mustard (*Brassica juncea* L.) holds a remarkable historical significance as one of the oldest condiments, and its cultivation has been prevalent worldwide for thousands of years. The origins of mustard cultivation can be traced back to 3000 B.C. In India, mustard is the most important oilseed crop, ranking first in terms of cultivated area and second in production, trailing only China. The total area dedicated to rapeseed-mustard cultivation in India is approximately 5.98 million hectares, with a production of 8.32 million tonnes and ~~a~~ productivity of 1397 kg per hectare (Anonymous, 2019). Oilseeds, including rapeseed-mustard, hold a significant share of 14.1 percent ~~in~~ of the total cropped area of the country. Specifically, rapeseed-mustard alone occupies 3 percent of the total cropped area. Among the seven edible oilseeds cultivated in India, mustard is the principal edible oilseed crop, contributing 28.6 percent to the overall oilseed production. It stands as the second-largest oilseed crop in the country, following groundnut, which accounts for 27.8 percent of India's oilseed economy. The cultivation of mustard is primarily concentrated in states such as Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat, and certain non-traditional regions in southern India. These regions play a vital role in mustard production and contribute significantly to the overall oilseed sector in the country (Singh *et al.*, 2017).

Nitrogen plays a vital role in plant growth and development, making it an essential nutrient for plants. It is an integral component of amino acids, proteins, chlorophyll, and nucleic acids, which are crucial for various metabolic processes. Nitrogen availability in the soil greatly influences plant productivity and overall crop yield. In Indian soil, nitrogen holds significant importance due to its impact on agricultural sustainability and food security. However, many Indian soils are inherently low in nitrogen content, necessitating external nitrogen inputs through fertilizers to meet the demands of high-yielding crop varieties. The efficient management of nitrogen is crucial to optimize crop production while minimizing environmental impacts such as nitrate leaching and greenhouse gas emissions. Nitrogen is a critical element that significantly influences agricultural production on a global scale. Despite numerous efforts, the efficiency of nitrogen use (NUE) in agriculture remains relatively low, typically falling below 50%. Among all mineral nutrients, nitrogen stands out as the foremost requirement for crop plants. It serves as a vital component of chlorophyll, proteins, and enzymes, playing a pivotal role in promoting vegetative growth in crops. Unfortunately, nitrogen losses occur through various processes, including nitrate leaching, denitrification, and ammonia volatilization. These losses not only result in economic losses but also raise concerns regarding environmental pollution. The loss of mineral nutrients through leaching and runoff, coupled with significant volatilization, is particularly alarming. Furthermore, nitrogen volatilization leads to the release of nitrous oxides, contributing to the greenhouse effect and global warming. It is disheartening to observe that modern profit-driven farming systems exhibit nitrogenous fertilizer use efficiency of only 45-50%, highlighting the need for improved practices and sustainable approaches in nitrogen management.

Zinc is recognized as the fourth most crucial nutrient that limits crop yield, following nitrogen, phosphorus, and potassium, both globally and in Indian soils (Arunachalam *et al.,* 2013). It has been estimated that approximately 36.5% of Indian soils suffer from zinc deficiency (Arvind *et al.*, 2019). Zinc is an essential micronutrient for crop nutrition as it plays a pivotal role in various metabolic processes, including the synthesis and degradation of carbohydrates, nucleic acids, lipids, and proteins. It serves as a fundamental component of nearly 200 enzymes in plants. Additionally, zinc is involved in the synthesis of Indole Acetic Acid (IAA), a phytohormone that exerts significant control over plant growth, chlorophyll synthesis, pollen formation, and tolerance to environmental stress. Moreover, zinc influences water uptake and transport within the plant. Given its multifaceted roles, ensuring an adequate supply of zinc is critical for optimizing plant growth and development, enhancing crop productivity, and mitigating the effects of environmental stressors.

Foliar application is a technique that involves the direct spraying of liquid fertilizers onto plant leaves, enabling better absorption in the aerial parts (Nasiri *et al.,* 2010; Marzouk *et al.,* 2019). This method has proven to be more effective than soil fertilizer application, particularly under conditions of drought and salinity. ~~Foliar~~ The foliar application allows nutrients to be supplied directly to the leaves, facilitating rapid absorption. It is independent of root activity and the availability of soil water (Romheld and El-fouly, 1999). When it comes to grain crops, such as wheat, the application of foliar nano zinc, copper, and iron fertilizers has been shown to enhance growth parameters when compared to other fertilizer sources (Ghorbanpour *et al.,* 2017).

Nano fertilizers have emerged as a promising approach to promoting plant growth and enhancing crop production. These fertilizers deliver essential nutrients in a nano form, offering advantages such as high fertilizer~~s~~ use efficiency, ultrahigh absorption due to their small size, and the ability to minimize negative effects associated with over-dosage. By utilizing nano fertilizers, the frequency of fertilizer application can be reduced, leading to cost savings. Additionally, the decline in environmental protection costs further contributes to their cost-effectiveness. Moreover, nano fertilizers help maintain soil fertility and health, making them an eco-friendly alternative to conventional fertilizers. They hold great potential for sustainable agriculture and the production of high-quality food, while minimizing adverse impacts on human health and the environment (Sekhon, 2014).

Given the challenges posed by a growing population and increasing food demand within limited land resources, improving nutrient use efficiency and adopting innovative technologies are crucial for ensuring food availability (Naderi and Shahraki, 2013). Nano-fertilizers offer a controlled and targeted release of nutrients into the soil, minimizing nutrient losses and soil toxicity. By utilizing nano-fertilizers, the sustainability and protection of agriculturally produced food can be maintained while reducing environmental impacts (Arif *et al.*, 2016). The application of nano-fertilizers provides an opportunity to address the challenges of agricultural productivity, food security, and environmental sustainability in a more efficient and responsible manner.

In light of the aforementioned information, the current study was conducted to assess the effects of foliar applications of nano nitrogen- and zinc on soil properties after the harvest of mustard crops in the sub-humid southern plains of Rajasthan.

2. MATERIALS AND METHODS

2.1 Study area

The experiment was conducted during rabi 2021-22 at the Instructional Farm, Rajasthan College of Agriculture, Udaipur. The region falls under the agro-climatic zone-IVA (Sub-humid Southern Plains and Aravalli Hills) of Rajasthan. The climate of the study area is sub-humid with an average minimum and maximum temperature (October-February) ranging between 3.2^{o} to 30.4^{o}C.

To ascertain the physico-chemical characteristics of the experimental field, soil samples up to 0-15 cm depth were drawn from different spots of the field, and a representative composite sample was prepared by mixing, which was subjected to mechanical, physical, chemical, and biological analysis using standard methods. Table 1 presents the results of the soil analysis along with the protocol used. The data indicate that the soil of the experimental site was clay loam, neutral alkaline in reaction, medium in available nitrogen and phosphorus and high in available potassium, and sufficient in DTPA extractable micronutrients.

2.2 Experimental ~~d~~D~~esign~~ Design and treatments

The experiment was laid out in a randomized block design with three replications. The gross plot size was 15 m^2 (5 x 3 m). The experiment consisted of ten treatments *viz.*, T_1

(Control), T_2 (100% NPK Zn), T_3 (75% N Zn + 100 % PK), T_4 (50% N Zn + 100 % PK), T_5 (T_2+1st spray of Nano N and Zn at 30 DAS), T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS), T_7 (75% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS), T_8 (75% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS), T_9 (50% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS), T_{10} (50% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) ~~were~~ was applied to mustard var. Giriraj (DRMRIJ 31) in *rabi* session, 2021-22. In accordance with the recommended practices outlined in the Package of Practices by the Government of Rajasthan, the fertilizer application was carried out using the recommended dosage. For the specified area, the recommended fertilizer doses were 60 kg of nitrogen (N), 40 kg of phosphorus pentoxide (P_2O_5), 40 kg of potassium oxide (K_2O), and 5 kg of zinc sulfate ($ZnSO_4$) per hectare (ha). These doses were applied to meet the nutrient requirements of the crops effectively.

2.3 Application protocol of foliar spray

The foliar sprays were administered in the selected treatments by utilizing a knapsack sprayer equipped with a flat fan nozzle. The application schedule involved two sprays: the first spray was applied 30 days after sowing, while the second spray was administered at 45 days after sowing. For the specified treatments, the foliar spray consisted of Nano N at a rate of 4 ml per liter of water, while Nano Zn was applied at a rate of 2 ml per liter of water. The sprays were applied according to the predetermined treatment schedule.

2.4 Soil Chemical Properties

To assess the fertility status of soil, the soil sample (0-15 cm depth) from each plot at harvest of the crop was taken. The samples were passed through a 2 mm plastic sieve to avoid metallic contamination. The soil sample ~~were~~ was analyzed for available N, P, K, and available micronutrients (Zn, Fe, Mn, and Cu) as per the method given below.

Chemical determinations

(a)	Available nitrogen	By alkaline permanganate method	Subbiah and Asija (1956)
(b)	Available Phosphorus	Extraction of soil with 0.5 M $NaHCO_3$ at pH 8.5 and development of blue colour with $SnCl_2$. and measurement through colorimetrically	Olsen *et al.* (1954)
(c)	Available potassium	Extraction was done with 1 N neutral ammonium aceate at pH 7.0 and determined by flame photometer	Richards (1954)

(d)	Available Zn, Fe, Mn, and Cu	Analysis of suitable aliquot of DTPA extract with the help of atomic absorption spectro-photometer (Varian techtron AAS-120)	Lindsay and Norvell (1978)

2.5 Soil microbial properties

Soil samples (0-15 cm depth) were collected at harvest of the crop from each treatment plot for analysis. The samples were stored in plastic bags and taken to the laboratory, where the soil was sieved (2 mm mesh size), homogenized, and stored at 4°C. The fungal, bacterial, and actinomycetes populations ~~were~~ was estimated by standard plate count method using Marten’s for fungi (Martin, 1950), and nutrient agar medium for bacteria and actinomycetes (Allen, 1959). ~~Microbial~~ The microbial population was calculated and expressed as a number of cells per gram of soil. Dehydrogenase enzyme activity in soil was evaluated by Anthrone extraction method (Casida *et al.*, 1964). Acid phosphatase activity in soil was determined by β-nitrophenol phosphate by spectrophotometry method (Tabatabai and Bremner, 1969).

2.6 Statistical Analysis

The statistical analysis of the obtained data was conducted using the analysis of variance (ANOVA) techniques, following the methodology outlined by Steel and Torrie (1960). To compare the treatment means, the critical difference (CD) test was employed at a significance level of 5% (P=0.05). The critical difference test helps determine the minimum significant difference between treatment means that indicates a statistically significant variation.

3. Result and Discussion

3.1 Chemical Properties

The application of foliar spray consisting of nano-sized nitrogen and zinc fertilizers has been found to have a significant impact on increasing the availability of nutrients such as nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) in the soil after the mustard crop is harvested. This information is presented in Table 2 and Table 3. Maximum available nutrient content in soil was observed under treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) which was statistically at par with T_8(75% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS) as compared to control. Nano-scale particles have a significantly larger surface area compared to their bulk counterparts. This increased surface area allows for greater interaction with soil particles and enhances the contact between the nanoparticles and soil nutrients. As a result, the release and availability of nutrients in the soil can be improved. Nano-scale particles can exhibit unique chemical properties compared to bulk materials (Zahoor *et al.*, 2018). Nano nitrogen and nano zinc particles can increase the solubility of nitrogen and zinc, respectively, in the soil. This increased solubility promotes the release of these nutrients, making them more accessible to plants and microorganisms (Rehman *et al.*, 2019). Nano nitrogen and nano zinc can interact with organic matter in the soil, such as humic and fulvic acids. These interactions can promote the decomposition of organic matter, thereby releasing bound nutrients and making them available to plants (Singh *et al.*, 2017). The increased availability of nutrients can be attributed to the unique properties of nano-sized nitrogen and zinc particles. These particles have a significantly larger surface area, allowing for enhanced absorption and utilization by plant roots. The foliar spray application facilitates direct contact between the nanoparticles and the plant surfaces, promoting efficient nutrient uptake (Singh *et al.*, 2020). According to Abdelsalam *et al.* (2019), their study on soybean demonstrated that the utilization of nano-sized nitrogen and zinc can enhance the efficiency of nutrient uptake in plants. These nanoparticles ~~have the ability to~~can increase the accessibility and availability of nutrients to plant roots, thereby improving nutrient absorption and utilization throughout the crop growth cycle. Consequently, this improved nutrient uptake can contribute to higher levels of nutrient content remaining in the soil following harvest. Abdel-Aziz *et al.* (2018) conducted a study that yielded similar findings, supporting the notion that foliar spray application of NPK (nitrogen, phosphorus, and potassium) can enhance the availability of nitrogen, potassium, and micronutrients. This improvement can be attributed to the ability of nano~~-~~particles to facilitate the release of nutrients from organic matter or mineral compounds present in the soil. The enhanced release of nutrients contributes to ~~a~~ greater availability of nutrients for uptake by plants, ultimately resulting in higher nutrient content in the soil following harvest.

3.2 Biological Properties

Foliar application of nano nitrogen and nano zinc significantly increased the soil microbial population (bacteria, fungi, and actinomycetes) in the soil after the mustard harvest (Table 4). The maximum microbiological population of bacteria (60.00 x 10^7 cfu g^{-1} of soil), fungi (26.67 × 10^5 cfu g^{-1} of soil), and actinomycetes (34.97 x 10^6 cfu g^{-1} of soil) ~~was~~ were found under treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). Nano-fertilizers stimulated the growth of microbes by providing nutrients in available soluble forms and directly increased the population. Nano-fertilizers stimulated the growth of microbes by providing nutrients in available soluble forms and directly increased the population. The application of nano-fertilizers appears to be safer and due to proper availability of nutrients improved both plant and microbial biomass. ~~Microbial~~ The microbial activity of a soil system is affected by anthropogenic activities such as indiscriminate use of chemicals. ~~Microbial~~ The microbial population decreases with an increase in levels of contaminants (Xie *et al.*, 2016). The enhancement in microbial population and activity in rhizosphere may also enhance nutrient mobilization and availability of nutrients for plant~~s~~ uptake (Pandey *et al.*, 2010). ~~Similar~~ A similar result was shown by Meena *et al*. (2021) that a significant maximum microbial count of bacteria (78.54 × 10^6), fungi (34.25 × 10^4), and microbial biomass-C (259.33 mg kg^{-1}) was obtained under foliar application of nano nutrients. According to Nibin *et al.* (2019) research, nano NPK was applied foliarly to bhindi, which increased the microbial population's activity. According to Rajput *et al.* (2018), nano fertilizers improved the amount of accessible nutrients and microbial population in soil following crop harvest. According to the findings of Hu et al. (2015), the application of nano-sized zinc and nitrogen has been shown to have a significant impact on plant health and growth. This improved plant health can result in the secretion of root exudates and increased organic matter production, which serves as a food source for soil microbes. The enhanced plant growth resulting from the application of nanomaterials can indirectly contribute to the proliferation of microbial populations by creating a more favorable environment for microbial colonization and activity.

~~Application~~ The application of foliar spray of nano-fertilizer significantly influenced the dehydrogenase activity and acid phosphatase activity in the soil after the harvest of the mustard crop (Table 5). The significant maximum dehydrogenase activity (20.83 µg TPF g^{-1} 24h^{-1} soil) and acid phosphatase activity (11.91 µg PNP g^{-1} h^{-1} soil) in the soil after harvest was found under treatment T_6 (100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS). Arif *et al.* (2019) found that increased microbial population activity has a direct positive impact on the activity of soil enzymes. The presence of nano-scale particles can stimulate the growth and activity of soil microbial populations, subsequently leading to elevated enzyme activity. Dehydrogenase and acid phosphatase enzymes, which play crucial roles in soil processes, are primarily produced by microbes. The application of nanomaterials creates a more conducive environment for microbial growth, thus promoting higher enzyme production and activity in the soil. Rai and Tripathi (2017) concluded that nano zinc and nano nitrogen application can improve plant growth and health. Healthy plants release root exudates that provide a carbon source for soil microbes, promoting microbial growth and enzyme production. Increased microbial activity due to nanomaterial application can subsequently enhance dehydrogenase and acid phosphatase activity in the soil.

4. Conclusion

Based on the aforementioned findings, it can be inferred that the foliar application of nano nitrogen and nano zinc not only enhances the availability of nutrients but also improves the population of soil microorganisms and their enzymatic activity in the post-harvest condition of the soil. Nano-fertilizers exhibit potential as an effective nutrient delivery system, thereby reducing the overall nutrient requirement. Soil enzymes are regarded as reliable indicators of microbial diversity in soil and their presence enhances the efficacy of applied nutrients as well as nutrients present in the labile pool. These results shed light on the potential utilization of nano-fertilizers for the safer and more efficient delivery of essential nutrients to crop plants in an environmentally favorable manner.

6. References

Abdel-Aziz H.M.M., N.A.H. Mohammed and M.O. Aya. 2018. Effect of foliar application of nano chitosan NPK fertilizer on the chemical composition of wheat grains. *Egyptian Journal of Botany*, **58**: 87 - 95.

Abdelsalam, E., Wafa, A. A., Alrumman, S. and Abdelrahman, H. M. 2019. Influence of zinc nanoparticles on the nutrient availability and productivity of soybean (*Glycine max* L.). *Journal of Soil Science and Plant Nutrition*, **19**(1): 69-79.

Allen, O.N. Experiments in Soil Bacteriology. 3 Edn., Burgess Publishing Co., Minneapolis, USA (1959).

Anonymous, 2019. Rajasthan Agricultural Statistics at a glance, Commissionerate of Agriculture, Jaipur, Rajasthan, 88.

Arif, N., Yadav, V., Singh, A., Singh, S. and Mishra, S. 2019. Effect of nano-zinc and nano-nitrogen on soil enzyme activities and nutrient availability in maize crop., *International Journal of Current Microbiology and Applied Sciences*, **8**(11): 2079-2088.

Arif, N., Yadav, V., Singh, S., Singh, S., Mishra, R. K., Sharma, S. and Chauhan, D. K. 2016. Current trends of engineered nanoparticles (ENPs) in sustainable agriculture: an overview. *Journal of Environmental & Analytical Toxicology*, **6**(5): 927-932.

Arunachalam, P., Kannan, P., Prabukumar, G., and Govindaraj, M. 2013. Zinc deficiency in Indian soils with special focus to enrich zinc in peanut. *African Journal of Agricultural Research*, **8**(50): 6681-6688.

Arvind, R., Singh, S. K., Kumar, V., Singh, S. P., Shukla, A., Nidhi and Yadav, R. C. 2019. Zinc fertilization in rice-wheat cropping system under upland calcareous soil. *Journal of Plant Nutrition*, **42**(3): 296-306.

Black, C. A. 1965. Methods of soils analysis Part II, Chemical and microbial properties. American Society of Agronomy Inc., Madison.

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal*, **54**: 464-465.

Casida Jr, L. E., Klein, D. A. and Santoro, T. 1964. Soil dehydrogenase activity. *Soil science*, **98**(6): 371-376.

Ghorbanpour M, Manika K. and Varma A. 2017. Nanoscience and Plant– Soil Systems. *Springer International Publishing.*

Hu, J., Wu, F., Wu, S., Cao, Z., Jiang, X., Chen, D., & Luo, Y. (2015). Effects of nano-ZnO on the agronomically relevant Rhizobium-legume symbiosis. *Science of The Total Environment*, **518**: 1-7.

Jackson, M. L. 1973. Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Lindsay, W. L. and Norvell, W. L. 1978. Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society and American Journal*, **42**: 421-442.

Martin, J.P.: Use of acid rose Bengal and streptomycin in the plate method for estimating soil fungi. *Soil Science*, **69**, 215–232 (1950).

Marzouk, N. M., Abd-Alrahman, H. A., EL-Tanahy, A. M. M., & Mahmoud, S. H. 2019. Impact of foliar spraying of nano micronutrient fertilizers on the growth, yield, physical quality, and nutritional value of two snap bean cultivars in sandy soils. *Bulletin of the National Research* Centre, **43**(1): 1-9.

Meena, R. H., G. Jat and D. Jain. 2021. Impact of foliar application of different nano-fertilizers on soil microbial properties and yield of Wheat. *Journal of Environmental Biology*, **42**: 302-308.

Naderi, M. R. and Shahraki, A. 2013, Nanofertilizers and their roles in sustainable agriculture. *International Journal of Agriculture and Crop Sciences*, **5**(19): 2229-2232.

Nasiri, Y., S. Zehtab-Salmasi, S. Nasrullahzadeh, N. Najafi and K. Ghassemi-Golezani, 2010: Effects of foliar application of micronutrients (Fe and Zn) on flower yield and essential oil of chamomile (*Matricaria chamomilla* L.). *The Journal of Medicinal Plants Research*, **4**: 1733-1737

Nibin, P. M., Ushakumari, K. and Ishrath, P. K. 2019. Organic nano NPK formulations on soil microbial and enzymatic activities on post-harvest soil of Bhindi. *International Journal of Current Microbiology and Applied Sciences*, **8**: 1819-1814.

Olsen, S. R., Cole, C. V., Watanable, F. S. and Dean. L. A. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U.S.D.A, 939, USA.

Pandey, A. K., Dastager, S. G. and Deepa, C. K. 2010. Isolation and characterization of plant growth promoting bacteria from non-rhizospheric soil and their effect on cowpea (*Vigna unguiculata* (L.) Walp.) seedling growth. *World Journal of Microbiology and Biotechnology*, **26**(7): 1233-1240.

Piper, C. S. 1950. Soil and plant analysis. Adelaide, Australia University of Australia, pp. 59-74.

Rai, R. and Tripathi, P. (2017). Effect of nano zinc oxide and nano magnesium oxide particles on growth, physiology and enzymes activity of chickpea. *International Journal of Science and Research*, **6**(5): 1936-1940.

Rajput, V. D., Minkina, T., Sushkova, S., Tsitsuashvili, V., Mandzhieva, S., Gorovtsov, A., Nevidomskyaya, D. and Gromakova, N. 2018. Effect of nanoparticles on crops and soil microbial communities. *Journal of Soils and Sediments*, **18**: 2179-2187.

Rehman, M. U., Khalid, M., Amjad, M. and Shahzad, S. 2019. Effect of Nano-Nitrogen and Nano-Zinc Fertilizers on Nutrient Availability in Soil and Growth of Wheat. *International Journal of Agriculture and Biology*, **23**(3): 401-408.

Richards, L. A. 1954. Diagnosis and improvement of saline and alkaline soils. USDA, Hand Book No. 60.

Romheld, V. and El-Fouly, M. 1999. Foliar application of nutrients: challenges and limits in agricultural production. *Agronomic information*, **48**.

Scmidt, E. L. and Colwell, A. C., 1967. A practical manual of soil microbiology laboratory methods. Soil Bull, 7, FAO, Rome.

Sekhon, B. S. 2014. Nanotechnology in agri-food production: an overview. *Nanotechnology, Science and Applications*, **7**: 31.

Singh, A. K., Singh, A. K., Choudhary, A. K., Kumari, A. and Kumar, R. 2017. Towards oilseeds sufficiency in India: Present status and way forward. *Journal of Agri Search*, **4**(2): 80-84.

Singh, P., Singh, D. P. and Singh, V. P. (2017). Impact of Nano-Zinc and Nano-Nitrogen Fertilizers on Soil Nutrient Availability and Uptake by Rice. *Journal of Applied and Natural Science*, **9**(2): 1192-1198.

Singh, J., Lee, B. K. and Rinklebe, J. 2020. Nanotechnology for Sustainable Agriculture: Emerging Trends and Prospects. *Environmental Pollution*, **268**(Pt A): 115728.

Steel, R.G.D. and Torrie, J.H. 1960. Principles and procedures of statistics with special reference to the biological sciences, McGraw Hill, New York, :187-287.

Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, **25**: 259-260.

Tabatabai, M. A. and Bremner, J. M. 1969. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry*, **1**(4), 301-307.

Vance, E. D., Brookes, P. C. and Jenkinson, D. S. 1987. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry*, **19**(6): 703-707.

Walkley, A. J. and Black, I. A. 1934. Estimation of soil organic carbon by chromic acid titration method. *Soil Science*, **37**:29-38.

Xie, Y., J. Fan, W. Zhu, E. Amombo, Y. Lou, L. Chen and J. Fu. 2016. Effect of heavy metals pollution on soil microbial diversity and bermudagrass genetic variation. *Frontiers in Plant Science*, **7**:755.

Zahoor, M., Irshad, M., Yaseen, M., Akram, M., Rizwan, M., Ali, S. and Alyemeni, M. N. 2018. Effect of Nano-Zinc and Nano-Nitrogen on Nutrient Availability and Yield of Maize. *International Journal of Environmental Research and Public Health*, **15**(5): 1031.

Table 1. Mechanical, physic-chemical and biological properties of soil of the experimental field

Characteristics	Value	Method of analysis	Reference
A. Mechanical Composition			
Sand (%)	38.25%	By International Pipette Method	Bouyoucos (1962)
Silt (%)	26.94%		
Clay (%)	34.47%		
Soil texture	Clay loam		Piper (1950)
B. Physical Properties			
Bulk density (Mg m^{-3})	1.29	Core sampler method	Piper (1950)
Particle density (Mg m^{-3})	2.54		Black (1965)
Porosity (%)	49.21		
C. Chemical Properties			
Available N (kg ha^{-1})	250.13	Alkaline $KMnO_4$ method	Subbiah and Asija (1956)
Available P_2O_5 (kg ha^{-1})	26.05	Olsen's method	Olsen *et al.* (1954)
Available K_2O (kg ha^{-1})	415.04	Flame photometer	Jackson (1973)
Available Zn (mg kg^{-1})	0.52	DTPA-extract with AAS	Lindsay and Norvell (1978)
Available Fe (mg kg^{-1})	3.96		
Available Mn (mg kg^{-1})	8.70		
Available Cu (mg kg^{-1})	1.42		
Organic carbon (%)	0.52	Walkley and Black's rapid titration method	Walkley and Black (1934)
Electric Conductivity (dS m^{-1} at 25 °C)	0.78	Using soltbridge	Richards (1954)
pH (1:2 soil water suspension)	8.3	Glass electrode pH meter	Richards (1954)
D. Biological properties			
Bacterial population (cfu g^{-1} soil)	49.30 × 10^7	Standard serial dilution and plate count method	Scmidt and Colwell (1967)
Fungal population (cfu g^{-1} soil)	20.56 ×10^4		
Actinomycetes population (cfu g^{-1} soil)	30.12× 10^6		
Microbial biomass carbon (mg kg^{-1})	340 mg kg^{-1}	An extraction method for measuring soil microbial biomass carbon	Vance *et al.* (1987)

Table-2. Effect of Foliar Application of Nano Nitrogen and Nano Zinc on available N, P and K in soil after harvest of mustard

Treatments			**Available Nitrogen (kg ha^{-1})**	**Available Phosphorus (kg ha^{-1})**	**Available Potassium (kg ha^{-1})**
T_1	:	Control	245.33	17.88	265.57
T_2	:	100% NPK Zn	410.22	28.22	443.75
T_3	:	75% N Zn + 100% PK	364.34	26.00	393.25
T_4	:	50% N Zn + 100% PK	321.99	22.18	391.30
T_5	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	457.55	30.16	463.11
T_6	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	466.99	30.18	465.00
T_7	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	450.25	29.80	461.81
T_8	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	458.00	30.12	463.20
T_9	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	425.68	29.74	458.00
T_{10}	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	433.00	29.88	459.61
SEm±			5.207	0.519	6.524
CD (P =0.05)			15.471	1.542	19.383

Table 3. Effect of Foliar Application of Nano Nitrogen and Nano Zinc on Available Micronutrients in Soil after Harvest of Mustard

Treatments			Available Micronutrients (mg kg $^{-1}$)			
			Zinc	Iron	Manganese	Copper
T_1	:	Control	2.18	4.02	9.02	1.86
T_2	:	100% NPK Zn	3.64	4.41	9.89	1.92
T_3	:	75% N Zn + 100% PK	3.22	4.21	9.23	1.98
T_4	:	50% N Zn + 100% PK	2.89	4.15	9.10	2.00
T_5	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	4.07	4.22	10.02	2.26
T_6	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	4.18	5.62	10.22	2.20
T_7	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	4.07	5.21	10.01	2.10
T_8	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	4.09	5.02	10.25	2.17
T_9	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	3.86	4.27	10.00	2.03
T_{10}	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	3.86	4.52	9.98	2.05
SEm±			0.04	0.05	0.12	0.02
CD(P= 0.05)			0.12	0.17	0.37	0.06

Table 4. **Effect of Foliar Application of Nano Nitrogen and Nano Zinc on soil microbial population at harvest of mustard**

Treatments			**Microbial Population (cfu g^{-1} of soil)**		
			Bacteria (1×10^7)	**Fungi (1×10^5)**	**Actinomycetes (1×10^6)**
T_1	:	Control	53.93	23.06	31.48
T_2	:	100% NPK Zn	58.11	24.63	32.67
T_3	:	75% N Zn + 100 % PK	58.67	24.90	32.92
T_4	:	50% N Zn + 100 % PK	59.42	25.00	34.01
T_5	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	59.62	25.20	34.69
T_6	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	60.00	26.17	34.97
T_7	:	75% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS	59.40	24.11	33.68
T_8	:	75% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	59.22	24.19	33.92
T_9	:	50% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS	58.10	23.92	33.85
T_{10}	:	50% N Zn + 100 % PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	58.94	23.98	33.99
SEm±			0.608	0.225	0.608
CD(P= 0.05)			1.807	0.669	1.807

Table 5. Effect of Foliar Application of Nano Nitrogen and Nano Zinc on soil enzymic activity at harvest of mustard

Treatments			Dehydrogenase (µg TPF g^{-1} 24 h^{-1} soil)	Acid Phosphatase (µg of PNP g^{-1} h^{-1}soil)
T_1	:	Control	19.30	9.96
T_2	:	100% NPK Zn	20.03	11.63
T_3	:	75% N Zn + 100% PK	20.12	11.66
T_4	:	50% N Zn + 100% PK	20.50	11.79
T_5	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS	20.74	11.88
T_6	:	100% NPK Zn +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	20.81	11.91
T_7	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	20.40	11.75
T_8	:	75% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	20.47	11.78
T_9	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS	20.44	11.77
T_{10}	:	50% N Zn + 100% PK +1st spray of Nano N and Zn at 30 DAS +2nd spray of Nano N and Zn at 45 DAS	20.49	11.79
SEm±			0.143	0.053
CD(P= 0.05)			0.426	0.158

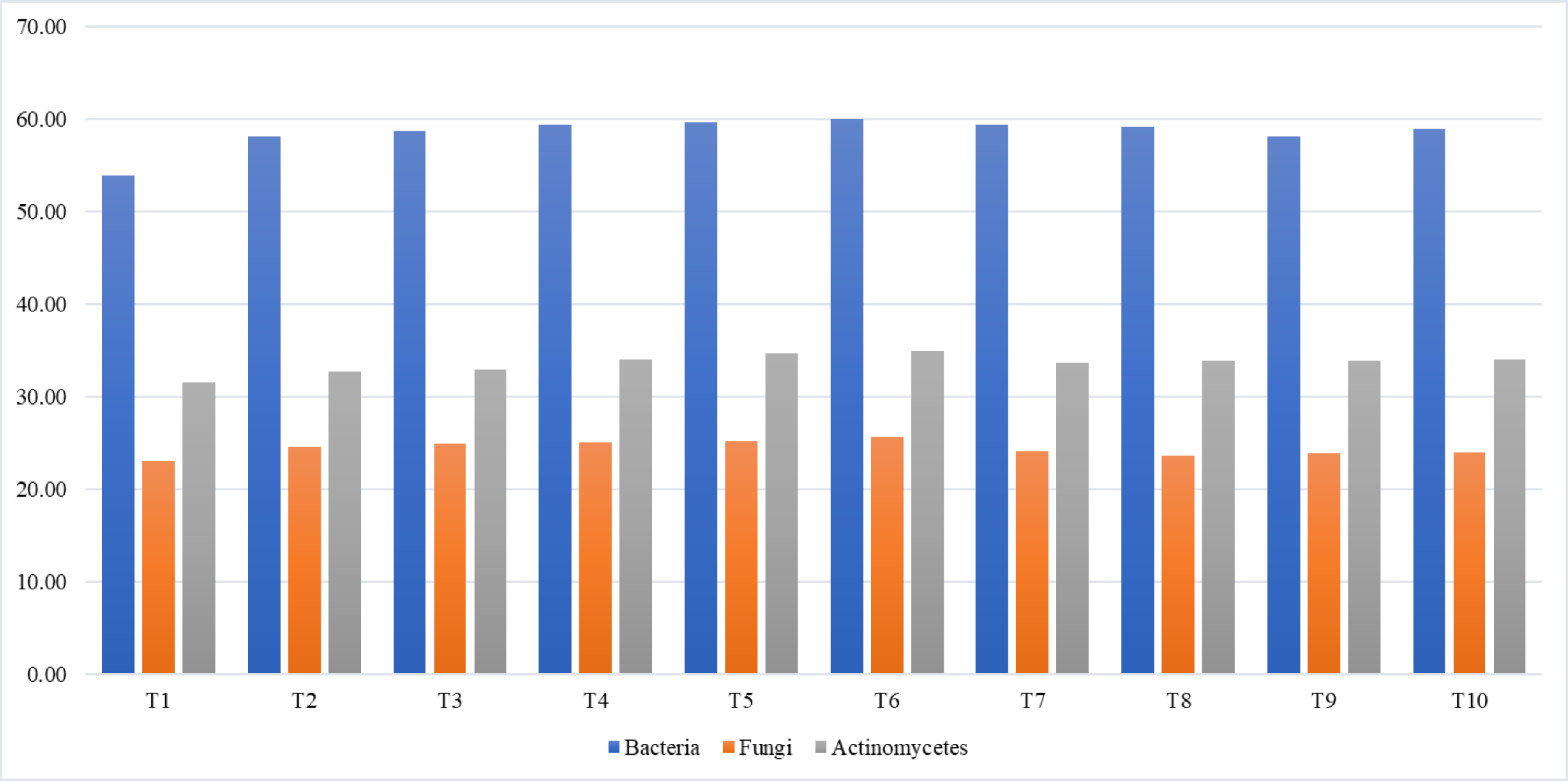

Fig. 1 Effect of Nano Nitrogen and Nano Zinc on soil microbial population in soil after harvest of mustard